Warming Trends in the Arctic from Clear Sky Satellite Observations

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ABSTRACT

Satellite thermal infrared data on surface temperatures provide pan-Arctic coverage from 1981 to 2001 during cloud-free conditions and reveal large warming anomalies in the 1990s compared to the 1980s and regional variability in the trend. The rms error of the derived surface temperatures when compared with in situ data ranges from 1.5 to 3 K over the 20-yr period. Average temperature trends are generally positive at 0.33 $\pm$ 0.16°C decade^{-1} over sea ice, 0.50 $\pm$ 0.22°C decade^{-1} over Eurasia, and 1.06 $\pm$ 0.22°C decade^{-1} over North America. The trend is slightly negative and insignificant at -0.09 ± 0.25°C decade^{-1} in Greenland with the negatives mainly at high elevations. The trends are also predominantly positive in spring, summer, and autumn causing the lengthening of the melt season by 10–17 days per decade while they are generally negative in winter. The longer-term in situ surface temperature data shows that the 20-yr trend is 8 times larger than the 100-yr trend suggesting a rapid acceleration in the warming that may be associated with the recent change in phase of the Arctic Oscillation that has been linked to increasing greenhouse gases in the atmosphere.

1. Introduction

The Arctic is expected to provide an early signal of global warming because of the amplification of the signal in the region due to feedback effects associated with the high albedo of snow and ice (Budyko 1966; Manabe et al. 1992). It is thus the appropriate region to examine the positive trends in global surface air temperatures reported previously (Raper et al. 1983; Hansen and Lebedeff 1987; Jones et al. 1999). Because of the paucity of station data in the Arctic and the presence of a dynamic sea ice cover, it has been difficult to assess quantitatively how surface temperature has been changing in the entire region. The lack of adequate temperature data north of 60°N latitude comes as no surprise because of the general inaccessibility of the Arctic, especially in winter. Some investigators have tried to remedy the situation by making use of data from buoys and meteorological stations since the late 1970s and apply spatial interpolations to fill in the gaps (Rigor et al. 2000). The resulting dataset from such an effort is a big improvement over previous records but some limitations in the interpolated data are apparent.

Arctic warming is suggested from recent reports of a retreating and thinning sea ice cover (Bjorgo et al. 1997; Parkinson et al. 1999; Rothrock et al. 1999; Wadhams and Davis 2000; Tucker et al. 2001). A rapidly declining perennial ice cover has also been reported recently (Comiso 2002) and 2002 has been cited as the year when the summer ice cover in the Arctic was least extensive during the satellite era (Serreze and Maslanik 2002, personal communication). To gain insight into this implied warming scenario through direct observations, two decades of satellite infrared data have been processed and analyzed in conjunction with in situ and other measurements. Under cloud-free conditions, infrared data provide skin depth (surface) temperatures and are shown to be generally consistent with surface air temperatures. The key source of historical surface temperature data is the Advanced Very High Resolution Radiometer (AVHRR) onboard National Oceanic and Atmospheric Administration satellites, which were processed as described previously (Comiso 2000, 2001). In this paper, we take advantage of such a truly global dataset to examine in spatial detail regional and interannual anomalies of surface temperature in the entire Arctic region, establish the spatial scope and persistence of such anomalies, and evaluate trends in surface temperature regionally and for the various seasons. Biases and possible effects on the trends, associated with having only cloud-free measurements, and interannual changes in cloud cover and aerosol are assessed.

2. Satellite observations of surface temperatures

When we think of global trends, we usually mean those that are derived from global averages. Such averages are more appropriately defined when obtained from satellite data that are able to provide large-scale

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synoptic and comprehensive observations of the entire region. Satellite thermal infrared data provide relatively accurate surface temperatures because the infrared emissivities of most surfaces (e.g., water, snow, and ice) are spatially uniform and close to unity. However, since infrared radiation is sensitive to clouds, surface measurements can be derived only during cloud-free conditions. A special cloud-masking technique had to be utilized in the processing of Arctic data because snow-covered surfaces and clouds have similar infrared signatures. In addition to the use of conventional thresholding techniques, a daily differencing technique was developed, as reported in Comiso (2000), by taking advantage of the large daily variability in the spatial distribution of clouds. The dataset provides detailed information about the distribution of surface temperature and has been successfully used to identify cooling trends in Antarctica (Comiso 2000) that were recently confirmed by studies using in situ data (Doran et al. 2002). The AVHRR temperature dataset has also been used successfully in spatially detailed correlation studies of Antarctic surface temperatures with Southern Oscillation indices and the climate anomaly in the Antarctic peninsula (e.g., Kwok and Comiso 2002; King and Comiso 2003).

To illustrate the effectiveness in reproducing surface temperatures from AVHRR data in the Northern Hemisphere, we make use of accurate in situ surface temperature datasets that have recently become available. One of these sets consists of surface temperatures acquired during the 1-yr-long ice station project Surface Heat Budget in the Arctic (SHEBA) (Perovich and Elder 2001) conducted in the central Arctic from October 1997 through September 1998. A comparison of these data with corresponding AVHRR data is shown in Fig. 1a and the results indicate good agreement, with an rms error of 1.58°C and a correlation coefficient of 0.992. These results are especially encouraging since both measurements in Fig. 1a reflect the temperature of a thin layer on the snow/ice surface during cloud-free conditions.

Clouds can cause a statistical bias on the monthly averages derived from AVHRR data. To quantify the magnitude of the cloud effect, we made use of continuous surface temperature measurements (with and without clouds) observed at the SHEBA station during September 1997 to October 1998. Actual monthly surface temperatures (i.e., combining cloudy and cloud-free surface data) are calculated and compared with monthly surface temperatures of cloud-free data only (with the cloud cover determined by the AVHRR data) and the results are presented in Fig. 1b. The results show a good agreement of the two monthly temperatures with a correlation coefficient of 0.997 and an rms error of 0.95°C. The average difference is about 0.07°C with the difference being negative at −0.27°C in autumn and −0.44°C in winter and positive at 0.94°C in spring and 0.03°C in summer. The negative values in autumn and winter may be a result of an atmospheric inversion, which is known to be prevalent during the period. In Greenland, the yearly average is −0.66°C consistent with similar studies in the Antarctic and stronger inversion effects at high elevations.

7. Conclusions

Two decades of satellite clear sky thermal infrared data show for the first time spatially detailed distribution of temperature anomalies in the pan-Arctic region from 1981 to 2000. The yearly anomalies are generally negative in the 1980s up to 1988 and generally positive after that. The change from negative to positive coincides with the observed change in phase of the AO. Trend analysis using monthly anomalies and yearly values shows a dominance of positive trends with the high positive values located in the western Arctic, but the spatial variation of this trend is large with negative values in the Greenland ice sheets and parts of Siberia. Quantitatively, the trends based on monthly anomalies (and also yearly means) are, on average, 0.33°C decade^{-1} over sea ice, −0.09° decade^{-1} over Greenland, 1.06°C decade^{-1} over North America, and 0.5°C decade^{-1} over northern Eurasia. Large variations in the monthly anomalies are observed but trend analysis based on yearly averages yields basically identical results.

Seasonally, the trends are mainly positive in summer, spring, and autumn when the impact on frozen surfaces is most critical. Unexpectedly, the trends are observed to be generally negative in winter, with some cooling observed in large areas in the Bering Sea and parts of Russia. The locations of negative trends in winter are consistent with those where positive trends in the sea ice cover have been identified (Parkinson et al. 1999). The length of the melt season is also observed to be increasing from 9 to 17 days decade^{-1} consistent with the apparent warming in the spring, summer, and autumn and suggesting a decreasing volume for the sea ice cover.

A sustained warming of the magnitude observed would cause profound changes in the Arctic region, especially in the sea ice cover, parts of the Greenland ice sheet, the permafrost, glaciers, and snow cover over northern Eurasia and North America. The longer-term station dataset also suggests acceleration in the warming rate but this may in part be caused but abnormally warm temperatures in the 1930s. Spectral analysis of the station data reveals a 12-yr cycle that is likely associated with the AO and NAO. The warming in recent decades has been attributed to increases in the positive phase of the AO/NAO, which in turn has been linked to the enhanced concentration of greenhouse gases in the atmosphere by Shindell et al. (1999), using a stratospheric-resolving climate model. The latter suggests that the observed warming in this study may not be natural in origin despite the observed decadal variability.